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Ekaterini Panopoulou
Department of Statistics and Insurance Science, University of Piraeus, Greece

Theologos Pantelidis
Department of Economics, National University of Ireland, Maynooth

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Department and Statistics of Insurance Science, University of Piraeus.

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**Abstract**

We examine convergence in carbon dioxide emissions among 128 countries for the period 1960-2003 by means of a new methodology introduced by Phillips and Sul (*Econometrica,* 2007). Contrary to previous studies, our approach allows us to examine for evidence of club convergence, i.e. identify groups of countries that converge to different equilibria. Our results suggest convergence in per capita $CO_2$ emissions among all the countries under scrutiny in the early years of our sample. However, there seems to be two separate convergence clubs in the recent era that converge to different steady states. Interestingly, we also find evidence of transitioning between the two convergence clubs suggesting either a slow convergence between the two clubs or a tendency for some countries to move from one convergence club to the other.

**JEL Classification:** C23; Q53.

**Keywords**: Convergence club; carbon dioxide emissions; nonlinear time-varying factor model; relative transition.

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* *Correspondence to:* Ekaterini Panopoulou, Department of Statistics and Insurance Science, University of Piraeus, 80 Karaoli & Dimitriou Str., 18534, Piraeus, Greece. E-mail: apano@unipi.gr. Tel: 0030 210 4142728. Fax: 0030 210 4142340.

# 1 Introduction

The effect of global warming on climate change is now more evident than ever before. As a result, environmental awareness has increased substantially over the past years. In response, scientific bodies and governments try to design international climate change strategies to mitigate global warming.

Carbon dioxide ($CO_2$) emissions are considered to be the main cause of greenhouse warming. The examination and understanding of the stochastic dynamics of $CO_2$ emissions is important for policymakers in order to evaluate the impact of carbon emissions to the environment and design efficient climate change proposals. Therefore, numerous studies in the literature investigate the statistical properties of international carbon emissions. In the '90s, most studies focus on the relation between income and $CO_2$ emissions.[1] In most cases, the results indicate the existence of an inverted U-shaped relation (known as Environmental Kuznets Curve, EKC) between economic development and environmental degradation (see, inter alia, Grossman and Krueger 1995, Schmalensee *et al.* 1998 and Dasgupta *et al.* 2002).[2] In other words, carbon emissions appear to increase with income in low-income regions and decrease with income in high-income regions.

Forecasting carbon emissions is also one of the main objectives in various studies. Among others, Holtz-Eakin and Selden (1995) and Schmalensse *et al.* (1998) generate long-term forecasts of $CO_2$ emissions based on panel data regressions. On the other hand, Aldy (2006 and 2007) investigates the future distribution of $CO_2$ emissions in the context of a Markov chain transition matrix. These forecasts are crucial for policymakers when predicting the potential impact of environmental policies. Other studies concentrate on energy efficiency. Specifically, they measure energy efficiency in separate industrial sectors by examining the convergence in each sector's $CO_2$ emissions in relation to output level (see, inter alia, Kim and Worrell 2002, Graus *et al.* 2007 and Persson *et al.* 2007). The analysis is usually based on physical intensity indicators that measure energy efficiency (see, e.g., Farla *et al.* 1997 and Worrell *et al.* 1997).

Recently, attention has been given to the examination of cross-country convergence in $CO_2$ emissions. The existence or not of cross-country convergence in $CO_2$ emissions is of considerable interest for policymakers as the assumption of convergence is inherent in the majority of the projection models used to prepare climate change policy proposals. Empirical studies implement a variety of econometric methodologies to investigate cross-country convergence in carbon emissions (see Section 2.2 for a short literature review). Each methodology examines the existence of a different type of convergence. In general, researchers in the growth and environmental literature consider three different types of convergence, namely beta convergence, sigma convergence and stochastic convergence.[3]

In this study, we examine convergence in per capita $CO_2$ emissions among 128 countries. Our paper makes two important contributions to the literature. First, we examine $CO_2$ emissions convergence by means of a new methodology introduced by Phillips and Sul (2007a, PS henceforth). The methodology is based on a nonlinear time-varying factor model that incorporates the possibility of transitional heterogeneity or even transitional divergence. Moreover, the methodology is robust to the stationarity properties of the series under scrutiny, i.e. it does not rely on any particular assumption concerning trend stationarity of stochastic nonstationarity.[4] Second, and more importantly, in the context of this methodology we are able to group countries into convergence clusters by means of a simple empirical algorithm. In other words, we can identify groups of countries that converge to different equilibria and moreover the approach allows individual countries to diverge. In this way, we can examine the relation between the convergence clusters and various economic characteristics. We can also try to identify the reasons of divergence for the countries that do not belong to any convergence group. It is obvious that the examination of the economic characteristics that lead to $CO_2$ emissions convergence is critical for policymakers.

Our results suggest that the per capita $CO_2$ emissions of all 128 countries under scrutiny converge in the early years of our sample. Countries are then divided into two separate convergence clubs in the recent period that converge to different steady states. However, our findings also indicate some transitioning between the two convergence clubs suggesting either a slow convergence between the two clubs or a tendency for some countries to change club. Finally, we examine convergence between countries that share common characteristics. We provide evidence of convergence between the EMU members and also convergence between the OECD members (at a slower speed compared to EMU countries). Moreover, high-income countries seem to converge and there is also slow convergence among the middle-income countries (at a very slow speed). On the other hand, the results show that low-income countries diverge.

The rest of the paper is organized as follows. Section 2 briefly presents the three different concepts of convergence employed in the literature and makes a short literature review. Section 3 describes the methodology we use to examine carbon emission convergence among 128 countries.

Section 4 describes the dataset and reports our empirical findings and Section 5 concludes the paper.

# 2 Literature Review

In this section, we provide a short literature review of studies that examine convergence in carbon dioxide emissions. Before presenting the literature review, we briefly present the various concepts of convergence considered in the literature.

## 2.1 Three Concepts of Convergence

The notion of convergence among countries is based on the assumption that these countries are initially in disequilibrium. Numerous papers discuss and debate on different kinds of convergence. In general, growth literature (and afterwards environmental literature) considers the following three different types of convergence.

1. **Beta convergence:** This concept of convergence, introduced by Baumol (1986), refers to a negative relation between the growth rate of the variable of interest and its initial level. Specifically, the simplest way to test for beta convergence in $CO_2$ emissions is in the context of the following cross-country regression:

$$y_i = c + \beta E_{0,i} + u_i \tag{1}$$

where $y_i$ is the average growth rate of $CO_2$ emissions for country $i$, $E_{0,i}$ is the initial level of $CO_2$ emissions for country $i$ and $u_i$ is the error term. In the context of (1), we have beta convergence if $\beta < 0$.[5] In other words, convergence occurs when countries with high initial level of per capita $CO_2$ emissions have lower emission growth rate than countries with low initial level of per capita $CO_2$ emissions. However, this approach has been heavily criticized by many researchers. For example, De Long (1988) and Quah (1993) show that the aforementioned regression tends to indicate convergence when convergence does not exist in reality. Moreover, the regression assumes the same rate of convergence for all countries.[6]

2. **Sigma convergence:** Sigma convergence, introduced by Barro and Sala-i-Martin (1990),[7] refers to a decrease over time in the cross-sectional variation of the variable of interest.

Typically, the sample standard deviation is used to measure variation. In general, beta and sigma convergence are different but related concepts, since beta convergence is a necessary but not a sufficient condition for sigma convergence (Sala-i-Martin (1996)).

3. **Stochastic convergence:** The concept of stochastic convergence goes back to Quah (1990) who suggested that it is of interest to examine the persistence of shocks on the variable of interest (per capita income in his case). A few years later, Carlino and Mills (1993 and 1996) introduced the concept of stochastic convergence which is a time-series notion of convergence. Specifically, stochastic convergence in carbon emissions suggests that the shocks in (the logarithm of) per capita carbon emissions relative to the average of the sample are temporary. More in details, a researcher can test for stochastic convergence by means of standard (panel) unit root tests where the variable tested is the logarithm of the relative carbon emissions. Stochastic convergence exists when the relative carbon emissions are trend stationary.[8] On the other hand, the existence of a unit root indicates that the effect of a shock is permanent causing divergence of the series from the sample mean.

## 2.2 Previous Studies

Strazicich and List (2003) use both cross-sectional regression test and panel unit root test to examine beta and stochastic convergence respectively. Both methodologies reject the null hypothesis of divergence for a group of 21 industrialized countries.[9] Westerlund and Basher (2007) use a sample of over a century data of $CO_2$ emissions to investigate stochastic convergence among 28 developed and developing countries.[10] Motivated by Banerjee *et al.* (2004) who report a tendency of some panel unit root tests to reject non-stationarity in the presence of cross-sectional dependence, they implement a panel unit root test that allows for dependence among the series under examination. The results favor convergence for the full set of 28 countries.[11]

On the other hand, Nguyen-Van (2005), using a non-parametric approach that examines the entire distribution of carbon emissions, examines convergence in carbon emissions among 100 countries. His results show no evidence of convergence for the whole sample but convergence still exists for the industrial countries. Similar results are reported by Aldy (2006) who implements a variety of econometric methodologies and finds no evidence of convergence for a set of 88 countries although he finds convergence among 23 OECD countries.[12] Contrary to the last two studies, Ezcurra (2007) finds evidence of a decline in the cross-countries disparities for a set of 87 countries. However, his analysis, based on the entire cross-country distribution, also suggests that convergence will not continue indefinitely. Romero-Avila (2007) also reports stochastic convergence among 23 industrialized countries by means of panel unit root tests that account for structural breaks. Finally, Stegman (2005) investigates the intra-distributional dynamics of a sample of 97 countries and finds little evidence of convergence.

# 3 Methodology

In this section, we outline the econometric methodology we employ to examine the existence of convergence among the carbon emissions of 128 countries. The methodology was introduced by PS in order to test for convergence in a panel of countries.[13] We also briefly discuss the clustering algorithm that allows us to classify countries into club convergence groups.[14]

## 3.1 The $\log t$ Test

Let us have panel data for a variable $X_{it}$, $i = 1, ...N$ and $t = 1, ...T$ where $N$ and $T$ are the number of countries and the sample size respectively. In our empirical study, $X_{it}$ stands for the natural logarithm of per capita $CO_2$ emissions.

Often $X_{it}$ is decomposed into two components, one systematic, $g_{it}$, and one transitory, $a_{it}$. So $X_{it}$ is written as follows:

$$X_{it} = g_{it} + a_{it} \tag{2}$$

PS transform (2) in a way that common and idiosyncratic components in the panel are separated. Specifically,

$$X_{it} = \left(\frac{g_{it} + a_{it}}{\mu_t}\right)\mu_t = \delta_{it}\mu_t, \text{ for all } i, t \tag{3}$$

In this way, the variable of interest, $X_{it}$, is decomposed in two components, one common, $\mu_t$, and one idiosyncratic, $\delta_{it}$, both of which are time-varying. This formulation enables testing for convergence by testing whether the factor loadings $\delta_{it}$ converge. To do so, PS define the relative transition parameter, $h_{it}$, as

$$h_{it} = \frac{X_{it}}{\frac{1}{N}\sum_{i=1}^{N} X_{it}} = \frac{\delta_{it}}{\frac{1}{N}\sum_{i=1}^{N} \delta_{it}}$$

which measures the loading coefficient $\delta_{it}$ in relation to the panel average and as such the transition path for the economy $i$ relative to the panel average.[15]

Next we construct the cross-sectional mean square transition differential $H_1/H_t$ where

$$H_t = \frac{1}{N}\sum_{i=1}^{N}(\widehat{h}_{it} - 1)^2$$

that measures the distance of the panel from the common limit. PS implement the following semiparametric model for $\delta_{it}$:

$$\delta_{it} = \delta_i + \frac{\sigma_i \xi_{it}}{L(t)t^a}$$

where $\xi_{it} \sim iid(0,1)$ across $i$, $L(t)$ is a slowly varying function, such as $\log(t)$, and $\alpha$ denotes the speed of convergence. This representation ensures that $\delta_{it}$ converges to $\delta_i$ for all positive values of $a$ (or even when $a = 0$). We can now formulate the null hypothesis of convergence as follows:

$$\mathcal{H}_0 : \delta_i = \delta \text{ and } \alpha \succeq 0$$

against the alternative

$$\mathcal{H}_A : \delta_i \neq \delta \text{ for some } i \text{ and/or } \alpha \prec 0$$

PS test $H_0$ in the context of the following log$t$ regression

$$\log(H_1/H_t) - 2\log L(t) = \widehat{c} + \widehat{b}\log t + u_t$$

where $L(t) = log(t+1)$.The fitted coefficient of $logt$ is $\widehat{b} = 2\widehat{\alpha}$, where $\widehat{\alpha}$ is the estimate of $\alpha$ in $\mathcal{H}_0$. The standard error of the estimates is calculated using a HAC estimator for the long-run variance of the residuals. In this study, we employ the Quadratic spectral kernel and determine the bandwidth by means of the Andrews (1991) data-dependent procedure. By employing the conventional t-statistic $t_b$, the null hypothesis of convergence is rejected if $t_b < -1.65$. In practice this regression is run after a fraction of the sample is removed. PS recommend starting the regression at some point $t = [rT]$, where $[rT]$ is the integer part of $rT$, and $r = 0.3$.[16]

Given that rejection of the null for the panel as a whole does not imply the absence of club convergence, PS go one step beyond and develop an algorithm for club convergence. We next briefly outline the basic steps of the respective algorithm.[17]

### 3.2 Club Convergence Algorithm

- Step 1 (Ordering): Order the members of the panel according to the last observation.

- Step2 (Core Group Formation): Calculate the convergence t-stat, $t_k$, for sequential *logt* regressions based on the $k$ highest members (Step 1) with $2 \leq k \leq N$. The core group size is chosen on the basis of the maximum $t_k$ with $t_k > -1.65$.

- Step 3 (Club Membership): Select countries for membership in the core group (Step 2) by adding one at a time. Include the new country (member) if the associated t-statistic is greater than zero (conservative choice). Check that the club satisfies the criterion for convergence.

- Step 4 (Recursion and Stopping): The countries not selected in the club formed in Step 3, form a complement group. Run the *logt* regression for this set of countries. If it converges, then these countries form a second convergence club. If not, Steps 1 to 3 should be repeated, in order to reveal some subconvergence clusters. If no core group can be found (Step2), then these countries display a divergent behavior.

# 4 Carbon Emission Convergence

This section presents our empirical results on convergence of per capita carbon emissions for a group of 128 countries. We first describe our dataset and then summarize our findings.

## 4.1 Data

The analysis is based on annual per capita $CO_2$ emissions (measured in metric tons) provided by the World Development Indicators (World Bank). The data include carbon dioxide emissions from solid, liquid and gas fuels and gas flaring. We exclude from the analysis (i) countries with nominal $CO_2$ emissions less than one millions tons in 2003 and (ii) all OPEC members. We end up with a balanced panel of 128 countries for the period 1960-2003. Thus, we have a total of 5632 observations. The countries under scrutiny are listed in Table 1 that also indicates the members of EMU and OECD. The countries are also classified into high-, middle- and low-income countries according to 2006 gross national income (GNI) per capita (Source: World Development Indicators database, World Bank, July 2007). Our empirical results are for the natural logarithm of per capita $CO_2$ emissions.

### 4.2 Empirical Results

We employ the $\log t$ test with the panel of per capita $CO_2$ emissions for 128 countries. Panel A of Table 2 reports the estimated value for $b$, together with the corresponding $t-$statistic. The point estimate of $b$ is $-0.154$ and the $t-$statistic indicates that the parameter is significantly less than zero suggesting divergence of the full group of 128 countries. This result confirms earlier findings by Nguyen-Van (2005), Stegman (2005) and Aldy (2006) that report divergence among large groups of countries containing both developed and developing countries. However, theoretical and Monte Carlo results presented by PS show that the $\log t$ test has power against cases of club convergence. Thus, contrary to previous studies, our methodology allows us to investigate the possibility of a club convergence pattern among the countries under scrutiny.

We now implement the algorithm described in Section 3.2 to examine whether there are any subgroups of countries that converge. The results, presented in the left part of Table 3, initially indicate the existence of four convergence clubs, while there is no evidence of countries that diverge. The four clubs consist of 41, 17, 8 and 62 members respectively. Note that although the point estimate of $b$ is negative for the third and forth club, the $t-$statistic suggests that both estimates are not statistically different from zero.

Figure 1 illustrates the relative transition paths for the four different clubs calculated as the cross-sectional mean of the members of each club. The plot shows evidence of convergence among the first three clubs, while the fourth club seems to follows a different path. We can formally test for convergence among the initial four clubs to check whether they can be merged to form larger convergence clubs. Specifically, we first test for convergence between two consecutive clubs. The results, reported in the middle of Table 3 (headed "Tests of Club Merging"), reveal that clubs one and two form a larger convergence club and the same result holds for clubs two and three. On the other hand, the results show no evidence of convergence between clubs three and four. Moreover, motivated by these results, we also test whether there is convergence between the first three clubs. The estimated value of $b$ is 0.653 and it is statistically greater than zero and thus the test suggests that the first three clubs can form a large convergence club of 66 countries. In summary, we end up with two convergence clubs (club $1-2-3$ and club 4 reported in Table 4) consisting of 66 and 62 members respectively. In general, club $1-2-3$ contains the countries with high per capita $CO_2$ emissions and club 4 mostly contains countries with low per capita $CO_2$ emissions. Convergence among the members of club $1-2-3$ is faster compared to convergence among the members of club 4 as indicated by the higher estimate of $b$.

Figure 2 plots the relative transition paths for random members of the two convergence clubs.[18] It is evident that the members of the two convergence clubs converge to a different steady state.

Next, we examine the intertemporal dynamics of per capita $CO_2$ emissions by repeating the analysis for two different periods. Specifically, the first period is 1960 to 1985 and the second period goes from 1975 up to 2003. There are two reasons for our choice of the two periods. First, we wanted to have enough observations in each period which would enable us to reveal any convergence dynamics. Second, we wanted the second period (i.e. the more recent one) to concentrate on the period after the oil crisis in the mid 1970s which may affect the behavior of the series under scrutiny. Note that the convergence test applied in this study discards the first 30 percent of the sample[19] and focuses on the latter part of the data (that is, the post-1982 period in our case which is definitely after the oil crisis of the 1970s).[20]

We first examine the data for the existence of convergence between the full set of countries under scrutiny. For the 1960-1985 period, the results, reported in Panel B of Table 2, suggest a $b$ parameter that is not statistically different from zero, thus suggesting convergence (probably at a very slow rate) in per capita carbon emissions among all countries.[21] On the other hand, there is no evidence of full convergence for the second subperiod as indicated by the results presented in Panel C of Table 2. The estimate of $b$ is $-0.380$ and statistically significant rejecting the null hypothesis of convergence among per capita carbon emissions of the 128 countries.

Next, we examine the existence of convergence clubs for the 1975-2003 period. The clustering algorithm initially classifies the countries into four clubs. The four clubs consist of 27, 41, 23 and 37 members respectively. Once again, there are no countries that diverge. Figure 3 shows the relative transition paths for the four clubs. There is some evidence of convergence between the first and third club. We proceed the analysis by testing for convergence between clubs. The results, presented in Table 5, suggest that the first three clubs form a larger convergence club of 91 countries. However, the speed of convergence among the 91 countries is very slow as indicated by the fact that the estimated $b$ is not statistically different from zero. On the other hand, the 37 members of the fourth club seem to converge rapidly. Figure 4 illustrates the relative transition paths for random members of the two convergence clubs. We observe that members of club $1-2-3$ behave similarly during the whole period converging to a steady state very slowly. On the other hand, there is higher variability in the behavior of the members of club 4 but there is strong evidence of convergence among them.

Another interesting issue to examine is whether there is evidence of transitioning between groups. In other words, we want to investigate if part of a convergence club tends to approach the other club. In order to examine this issue, we use the $\log t$ test for a group that contains 50 percent of the lowest members (in terms of the per capita carbon emissions in 2003) of club $1-2-3$ and 50 percent of the highest members of club 4. The results, reported in Table 6, strongly support transitioning between the two convergence clubs since the estimated $b$ equals 2.567 and it is significantly different from zero. A possible explanation of this finding is that there is slow convergence between the two clubs (i.e. club $1-2-3$ and club 4). An alternative explanation is that there is a tendency for some countries to move from one convergence club to the other.

In summary, the examination of the intertemporal dynamics in the behavior of per capita $CO_2$ emissions reveal that the single convergence club of the first period was later divided into two clubs. This is illustrated in Figure 5 that reports the members of each convergence club. However, there is also evidence of transitioning between the two convergence clubs in the recent period suggesting either a slow convergence between the two clubs or a tendency for some countries to change club.

As a final stage of our analysis, we examine convergence between countries that share common characteristics. More specifically, we test for convergence among (i) EMU members, (ii) OECD members, (iii) high-income countries, (iv) middle-income countries and (v) low-income countries.[22] The results for all five groups are reported in Table 7 and can be summarized as follows.

1. There is strong evidence of convergence between the 13 EMU members, since the estimated parameter of $b$ ($\widehat{b} = 0.919$) is statistically greater than zero. The convergence of the EMU members towards a steady state is illustrated in Figure 6 that plots the relative transition paths for the 13 countries. Even Luxembourg and Portugal that have the higher and lower per capita $CO_2$ emissions among the EMU members, converge to a common steady state.

2. A similar result holds for the OECD members. Once again, the $\log t$ test indicates convergence between the 30 countries. However, convergence is slower compared to the EMU case. Figure 7 illustrates the relative transition paths for the OECD countries.

3. As expected, the results for the high-income countries are almost identical to those for the OECD countries. There is evidence of convergence between the 39 countries as illustrated in Figure 8.

4. The results support convergence among the middle-income countries. However, the estimated $b$ is not statistically different from zero suggesting a slow rate of convergence.

5. Contrary to the previous cases, the null hypothesis of convergence is rejected for the low-income countries. Specifically, $\widehat{b}$ equals $-0.391$ and the corresponding $t-$statistic is $-2.427$ indicating divergence. This is evident from the relative transition paths shown at the left-hand side graph of Figure 9. However, we can still identify (by means of the clustering algorithm) a club of nine low-income countries that converge. The nine countries are Burkina Faso, Cote d'Ivoire, Ghana, Mozambique, Nepal, Niger, Tajikistan, Uganda and Zambia. The graph at the right-hand side of Figure 9 presents the relative transition paths for these nine countries.

## 5 Conclusions

Convergence in carbon dioxide emissions has attracted the interest of many researchers during the last five years. This study contributes to the existing literature by examining convergence in per capita $CO_2$ emissions between 128 countries for the period 1960-2003 by means of new methodology. Specifically, our analysis is based on a convergence test introduced by Phillips and Sul (2007a) and it has two important advantages compared to others methodologies. First, the methodology incorporates the possibility of transitional heterogeneity. Second, in cases where there is divergence for the full set of variables under scrutiny, our approach can be used to identify groups of countries that converge to different equilibria, while we can still allow individual countries to diverge.

Our results favor the existence of convergence for all 128 countries in the early period of our sample. For the recent years, there appears to be two convergence clubs, one containing countries with high per capita $CO_2$ emissions and one containing countries with low per capita $CO_2$ emissions. Interestingly, we find evidence of transitioning between the two convergence clubs suggesting either a slow convergence between the two clubs or a tendency for some countries to change club.

# Notes

[1]See, for example, Shafik (1994) and Ravallion *et al.* (2000).

[2]See also Brock and Taylor (2004) and Bulte *et al.* (2007) for an examination of the relation between EKC and the Solow growth model.

[3]The next section provides a detailed description of these types of convergence.

[4]The model also accommodates cases where a long-run comovement in aggregate behavior exists irrespective of the existence of cointegration.

[5]We can test for conditional beta convergence by augmenting equation (1) with appropriate additional explanatory variables. Then, conditional beta convergence occurs when $\beta < 0$.

[6]In a series of papers, Quah (1996, 1997) argues that beta convergence is uninformative for a distribution's dynamics and suggests an alternative approach to examine convergence based on the entire cross-country distribution.

[7]See also Barro *et al.* (1991).

[8]A closely related concept of convergence is the deterministic convergence which implies mean stationarity of the relative carbon emissions.

[9]List (1999) reports evidence of convergence in emissions of nitrogen oxides and sulfur dioxides among US regions by means of cross-sectional regressions and univariate unit root tests.

[10]Lanne and Liski (2004) examine a sample of per capita carbon emissions for 16 countries over a period of about 130 years trying to identify structural breaks in the slope of the trend. In most cases, the results suggested a single break in the beginning of the 20th century, while there is little evidence for a break during the oil-crises in the 1970s.

[11]The results of Heil and Selden (1999), based on panel unit root tests, suggest stationarity for a panel of 135 absolute $CO_2$ emissions.

[12]Following a similar approach, Aldy (2007) reports evidence of divergence in state-level emissions for the US.

[13]As noted by PS, the form of convergence is analogous to conditional sigma convergence.

[14]This algorithm was also put forward by PS and has been employed in Phillips and Sul (2005, 2007b).

[15]In Section 4, we refer to $h_{it}$ as the relative transition path of country $i$.

[16]Extensive Monte Carlo simulations conducted by PS shows that $r = 0.3$ is satisfactory in terms of both size and power.

[17]The reader is referred to PS for a more detailed description of the algorithm.

[18]Due to the large number of countries considered in this study, a figure with all 128 transition paths (one for each country) would have been confusing.

[19]As stated by Phillips and Sul (2005), "...(this approach) validates the regression equation in terms of the asymptotic representation of the transition distance and ensures test consistency in growth convergence applications".

[20]The results remain qualitatively similar for different choices of the two subperiods.

[21]This conclusion may be driven by the common effect of the oil crisis during the last period of the first subsample (i.e. in the 1970s).

[22]The members of each group are reported in Table 1.

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Table 1: Countries Included in the Analysis

| Country | Categories[&] | | | Country | Categories[&] | | | Country | Categories[&] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Albania | | | M | Guam | | | H | Niger | | | L |
| Argentina | | | M | Guatemala | | | M | Norway | * | | H |
| Armenia | | | M | Guinea | | | L | Pakistan | | | L |
| Australia | * | | H | Guyana | | | M | Panama | | | M |
| Austria | * | + | H | Haiti | | | L | Papua N. Guinea | | | L |
| Azerbaijan | | | M | Honduras | | | M | Paraguay | | | M |
| Bahrain | | | H | Hong Kong | | | H | Peru | | | M |
| Bangladesh | | | L | Hungary | * | | M | Philippines | | | M |
| Barbados | | | H | Iceland | * | | H | Poland | * | | M |
| Belarus | | | M | India | | | L | Portugal | * | + | H |
| Belgium | * | + | H | Ireland | * | + | H | Puerto Rico | | | H |
| Benin | | | L | Israel | | | H | Romania | | | M |
| Bolivia | | | M | Italy | * | + | H | Russian Feder. | | | M |
| Bosnia-Herzeg. | | | M | Jamaica | | | M | Senegal | | | L |
| Brazil | | | M | Japan | * | | H | Serbia-Monten. | | | M |
| Bulgaria | | | M | Jordan | | | M | Singapore | | | H |
| Burkina Faso | | | L | Kazakhstan | | | M | Slovak Republic | * | | M |
| Cameroon | | | M | Kenya | | | L | Slovenia | | + | H |
| Canada | * | | H | Korea, D. Rep. | | | L | South Africa | | | M |
| Chile | | | M | Korea, Rep. | * | | H | Spain | * | + | H |
| China | | | M | Kyrgyz Rep. | | | L | Sri Lanka | | | M |
| Colombia | | | M | Lao PDR | | | L | Sudan | | | L |
| Congo, D. Rep | | | L | Latvia | | | M | Suriname | | | M |
| Congo, Rep. | | | M | Lebanon | | | M | Sweden | * | | H |
| Costa Rica | | | M | Lithuania | | | M | Switzerland | * | | H |
| Cote d'Ivoire | | | L | Luxembourg | * | + | H | Syrian Arab Rep. | | | M |
| Croatia | | | M | Macao | | | H | Tajikistan | | | L |
| Cuba | | | M | F.Y.R.O.M. | | | M | Thailand | | | M |
| Cyprus | | | H | Madagascar | | | L | Togo | | | L |
| Czech Republic | * | | H | Malta | | | H | Trinidad-Tobago | | | H |
| Denmark | * | | H | Mauritania | | | L | Tunisia | | | M |
| Dominican Rep. | | | M | Mauritius | | | M | Turkey | * | | M |
| Egypt, Ar. Rep. | | | M | Mexico | * | | M | Turkmenistan | | | M |
| El Salvador | | | M | Moldova | | | M | Uganda | | | L |
| Estonia | | | H | Mongolia | | | L | Ukraine | | | M |
| Ethiopia | | | L | Morocco | | | M | United Kingdom | * | | H |
| Fiji | | | M | Mozambique | | | L | United States | * | | H |
| Finland | * | + | H | Myanmar | | | L | Uruguay | | | M |
| France | * | + | H | Nepal | | | L | Uzbekistan | | | L |
| Georgia | | | M | Netherlands | * | + | H | Vietnam | | | L |
| Germany | * | + | H | N. Caledonia | | | H | Yemen, Rep. | | | L |
| Ghana | | | L | New Zealand | * | | H | Zambia | | | L |
| Greece | * | + | H | Nicaragua | | | M | | | | |

[&] *:OECD member
+: EMU member
H: high-income country
M: middle-income country
L: low-income country

Table 2: Full Convergence Tests

| **Panel A: 1960-2003** | | **Panel B: 1960-1985** | | **Panel C: 1975-2003** | |
|---|---|---|---|---|---|
| log t | t-stat | log t | t-stat | log t | t-stat |
| -0.154* | -3.254 | 0.148 | 1.162 | -0.380* | -6.128 |

* indicates rejection of the null hypothesis of convergence at the 5% level

Table 3: Convergence Club Classification (period: 1960-2003)

| **Initial Classification** | | **Tests of Club Merging** | | | | **Final Classification** | |
|---|---|---|---|---|---|---|---|
| **Club 1[41]** | | | | | | **Clubs 1-2-3[66]** | |
| log t | t-stat | | | | | log t | t-stat |
| 1.334 | 21.580 | **Clubs 1-2[58]** | | | | 0.653 | 0.653 |
| **Club 2[17]** | | log t | t-stat | | | | |
| log t | t-stat | 0.839 | 11.260 | **Clubs 1-2-3[66]** | | | |
| 0.141 | 1.362 | **Clubs 2-3[25]** | | log t | t-stat | | |
| **Club 3[8]** | | log t | t-stat | 0.653 | 8.806 | | |
| log t | t-stat | 0.104 | 1.081 | | | | |
| -0.379 | -0.848 | **Clubs 3-4[70]** | | | | | |
| **Club 4[62]** | | log t | t-stat | | | **Club 4[62]** | |
| log t | t-stat | -2.350* | -8.484 | | | log t | t-stat |
| -1.131 | -0.783 | | | | | -1.131 | -0.783 |

* indicates rejection of the null hypothesis of convergence at the 5% level
The number of club members is reported in brackets.

Table 4: Convergence Clubs (1960-2003)

| **Club 1-2-3[66]** | | **Club 4[62]** | |
|---|---|---|---|
| Australia | Korea, Rep. | Albania | Latvia |
| Austria | Lebanon | Argentina | Lithuania |
| Bahrain | Luxembourg | Armenia | F.Y.R.O.M. |
| Bangladesh | Macao | Azerbaijan | Madagascar |
| Barbados | Malta | Belarus | Moldova |
| Belgium | Mauritania | Benin | Mongolia |
| Bosnia-Herzeg. | Mauritius | Bolivia | Mozambique |
| Burkina Faso | Mexico | Brazil | Myanmar |
| Canada | Morocco | Bulgaria | Nicaragua |
| Chile | Nepal | Cameroon | Niger |
| China | Netherlands | Colombia | Panama |
| Croatia | N. Caledonia | Congo, D. Rep | Papua N. Guinea |
| Cyprus | New Zealand | Congo, Rep. | Peru |
| Czech Republic | Norway | Costa Rica | Philippines |
| Denmark | Pakistan | Cote d'Ivoire | Puerto Rico |
| Dominican Rep. | Paraguay | Cuba | Romania |
| Egypt, Ar. Rep. | Poland | Ethiopia | Senegal |
| El Salvador | Portugal | Fiji | Serbia-Monten. |
| Estonia | Russian Feder. | France | Sri Lanka |
| Finland | Singapore | Georgia | Sudan |
| Germany | Slovak Republic | Ghana | Suriname |
| Greece | Slovenia | Guatemala | Sweden |
| Guam | South Africa | Guinea | Switzerland |
| Hong Kong | Spain | Guyana | Tajikistan |
| Iceland | Syrian Arab Rep. | Haiti | Togo |
| India | Thailand | Honduras | Uganda |
| Ireland | Trinidad-Tobago | Hungary | Ukraine |
| Israel | Tunisia | Jamaica | Uruguay |
| Italy | Turkey | Kenya | Uzbekistan |
| Japan | Turkmenistan | Kyrgyz Rep. | Vietnam |
| Jordan | United Kingdom | Lao PDR | Zambia |
| Kazakhstan | United States | | |
| Korea, D. Rep. | Yemen, Rep. | | |

The number of club members is reported in brackets.

Table 5: Convergence Club Classification (period: 1975-2003)

| **Initial Classification** | | **Tests of Club Merging** | | | | **Final Classification** | |
|---|---|---|---|---|---|---|---|
| **Club 1[27]** | | | | | | **Clubs 1-2-3[91]** | |
| log t | t-stat | | | | | log t | t-stat |
| 1.308 | 0.781 | **Clubs 1-2[68]** | | | | -0.048 | -0.505 |
| **Club 2[41]** | | log t | t-stat | | | | |
| log t | t-stat | -0.058 | -0.496 | **Clubs 1-2-3[91]** | | | |
| 0.269 | 5.788 | **Clubs 2-3[64]** | | log t | t-stat | | |
| **Club 3[23]** | | log t | t-stat | -0.048 | -0.505 | | |
| log t | t-stat | 0.014 | 0.152 | | | | |
| 0.620 | 4.669 | **Clubs 3-4[60]** | | | | | |
| **Club 4[37]** | | log t | t-stat | | | **Club 4[37]** | |
| log t | t-stat | -0.704* | -9.911 | | | log t | t-stat |
| 4.681 | 8.041 | | | | | 4.681 | 8.041 |

* indicates rejection of the null hypothesis of convergence at the 5% level
The number of club members is reported in brackets.

Table 6: Transition between Convergence Clubs (1975-2003)

| **Club 1-2-3 [lower 45] + Club 4 [upper 18]** | |
|---|---|
| log t | t-stat |
| 2.567 | 6.533 |

Table 7: Full Convergence Tests (1960-2003)

| **EMU[13]** | | **OECD[30]** | | **High-Income[39]** | | **Middle-Income[57]** | | **Low-Income[32]** | |
|---|---|---|---|---|---|---|---|---|---|
| log t | t-stat | log t | t-stat | log t | t-stat | log t | t-stat | log t | t-stat |
| 0.919 | 5.128 | 0.422 | 17.239 | 0.363 | 2.983 | 0.118 | 0.852 | -0.391* | -2.427 |

* indicates rejection of the null hypothesis of convergence at the 5% level
The number of club members is reported in brackets.

Figure 1: Relative Transition Curves of the Initial Convergence Clubs (1960-2003)

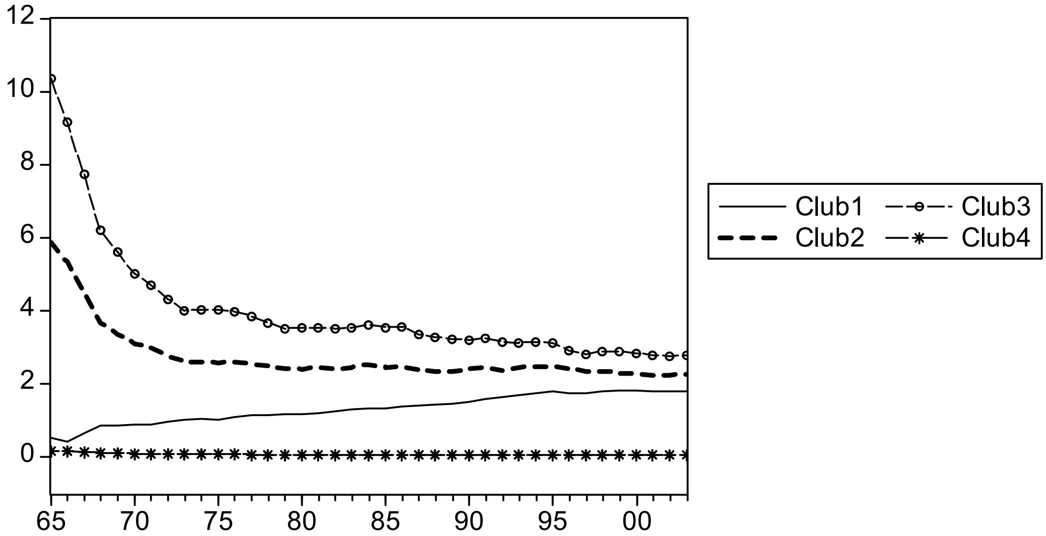



Figure 2: Examples of Convergence within Clubs (1960-2003)

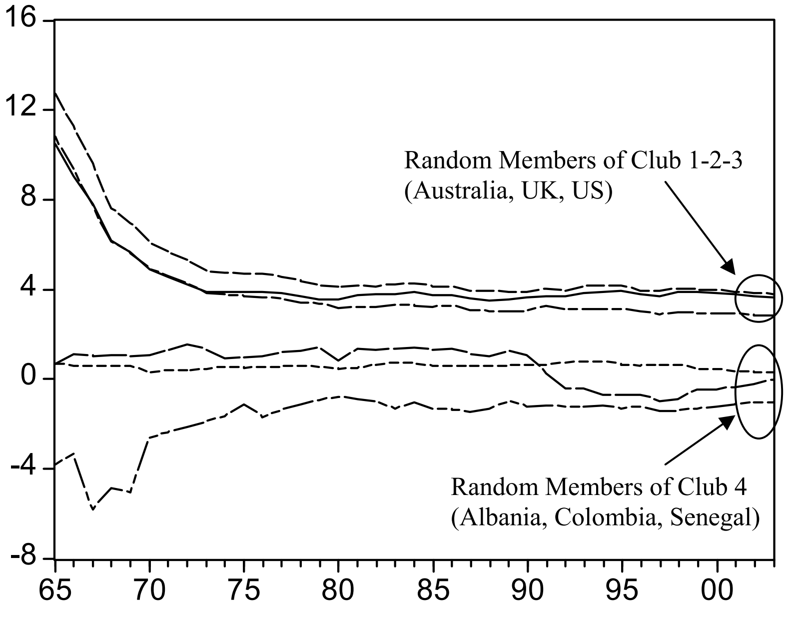


Figure 3: Relative Transition Curves of the Initial Convergence Clubs (1975-2003)

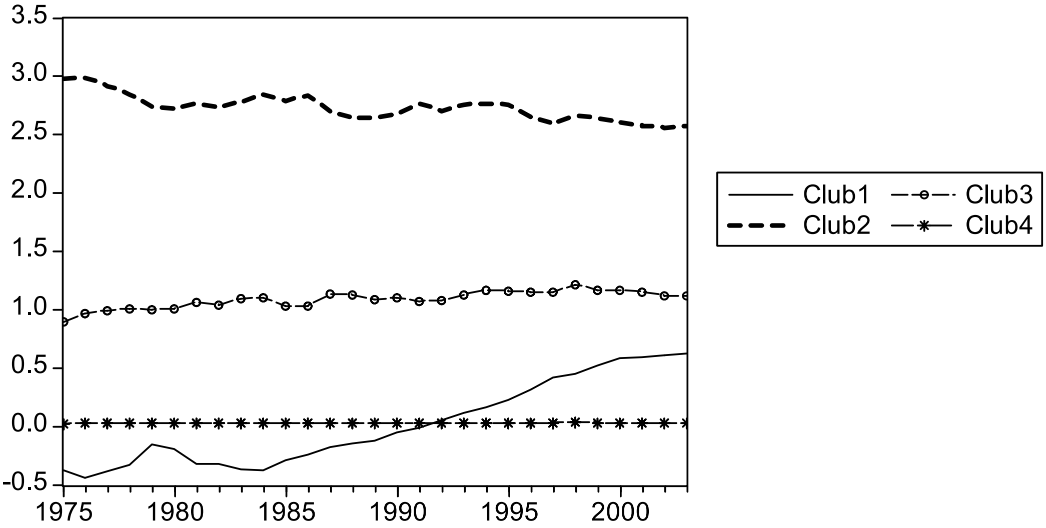



Figure 4: Examples of Convergence within Clubs (1975-2003)

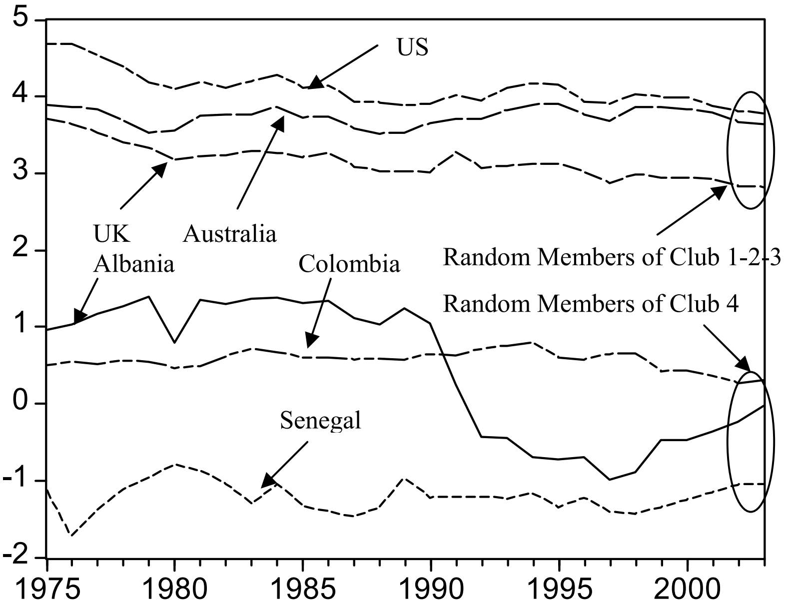


Figure 5: Intertemporal Dynamics of Convergence Clubs (1960-1985 v 1975-2003)

**1960-1975**
**(Single Club)**

Albania, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Barbados, Belarus, Belgium, Benin, Bolivia, Bosnia-Herzegovina, Brazil, Bulgaria, Burkina Faso, Cameroon, Canada, Chile, China, Colombia, Congo Dem. Rep., Congo Rep., Costa Rica, Cote d'Ivoire, Croatia, Cuba, Cyprus, Czech Republic, Denmark, Dominican Republic, Egypt Arab Rep., El Salvador, Estonia, Ethiopia, Fiji, Finland, France, Georgia, Germany, Ghana, Greece, Guam, Guatemala, Guinea, Guyana, Haiti, Honduras, Hong Kong, China, Hungary, Iceland, India, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Korea Dem. Rep., Korea Rep., Kyrgyz Republic, Lao PDR, Latvia, Lebanon, Lithuania, Luxembourg, Macao, F.Y.R.O.M., Madagascar, Malta, Mauritania, Mauritius, Mexico, Moldova, Mongolia, Morocco, Mozambique, Myanmar, Nepal, Netherlands, New Caledonia, New Zealand, Nicaragua, Niger, Norway, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Portugal, Puerto Rico, Romania, Russian Federation, Senegal, Serbia-Montenegro, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sri Lanka, Sudan, Suriname, Sweden, Switzerland, Syrian Arab Republic, Tajikistan, Thailand, Togo, Trinidad-Tobago, Tunisia, Turkey, Turkmenistan, Uganda, Ukraine, United Kingdom, United States, Uruguay, Uzbekistan, Vietnam, Yemen Rep., Zambia

**1975-2003**
**Club 1-2-3**

Argentina, Australia, Austria, Bahrain, Bangladesh, Barbados, Belarus, Belgium, Benin, Bolivia, Bosnia-Herzegovina, Brazil, Bulgaria, Burkina Faso, Canada, Chile, China, Costa Rica, Croatia, Cyprus, Czech Republic, Denmark, Dominican Republic, Egypt Arab Rep., El Salvador, Estonia, Ethiopia, Finland, France, Germany, Greece, Guam, Guatemala, Guinea, Guyana, Hong Kong, China, Hungary, Iceland, India, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Korea Rep., Lao PDR, Lebanon, Luxembourg, Macao, F.Y.R.O.M., Madagascar, Malta, Mauritania, Mauritius, Mexico, Morocco, Nepal, Netherlands, New Caledonia, New Zealand, Niger, Norway, Panama, Paraguay, Philippines, Poland, Portugal, Russian Federation, Serbia-Montenegro, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sri Lanka, , Suriname, Sweden, Switzerland, Syrian Arab Republic, Thailand, Togo, Trinidad-Tobago, Tunisia, Turkey, Turkmenistan, Uganda, Ukraine, United Kingdom, United States, Uzbekistan, Vietnam

**1975-2003**
**Club 4**

Albania, Armenia, Azerbaijan, Cameroon, Colombia, Congo Dem. Rep., Congo Rep., Cote d'Ivoire, Cuba, Fiji, Georgia, Ghana, Haiti, Honduras, Kenya, Korea Dem. Rep., Kyrgyz Republic, Latvia, Lithuania, Moldova, Mongolia, Mozambique, Myanmar, Nicaragua, Pakistan, Papua New Guinea, Peru, Puerto Rico, Romania, Senegal, Sudan, Tajikistan, Uruguay, Yemen Rep., Zambia

Figure 6: EMU-Members Relative Transition Paths

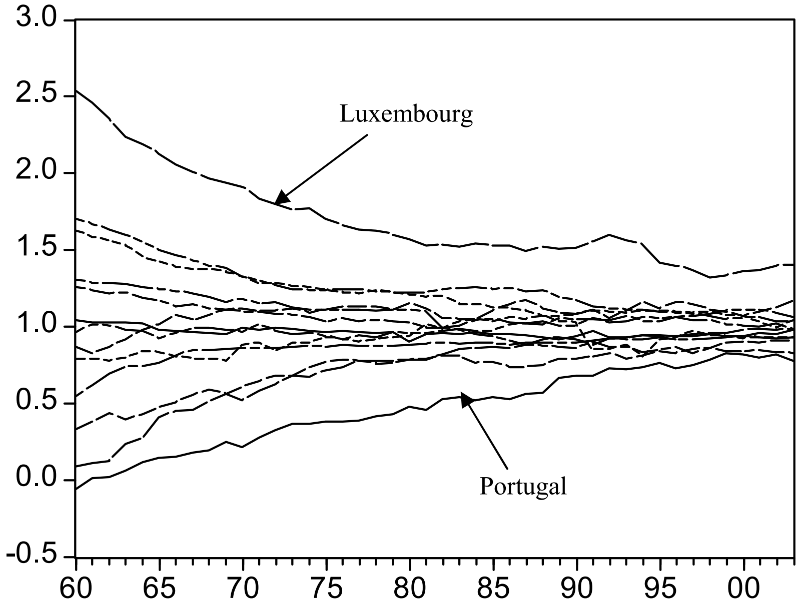



Figure 7: OECD-Members Relative Transition Paths

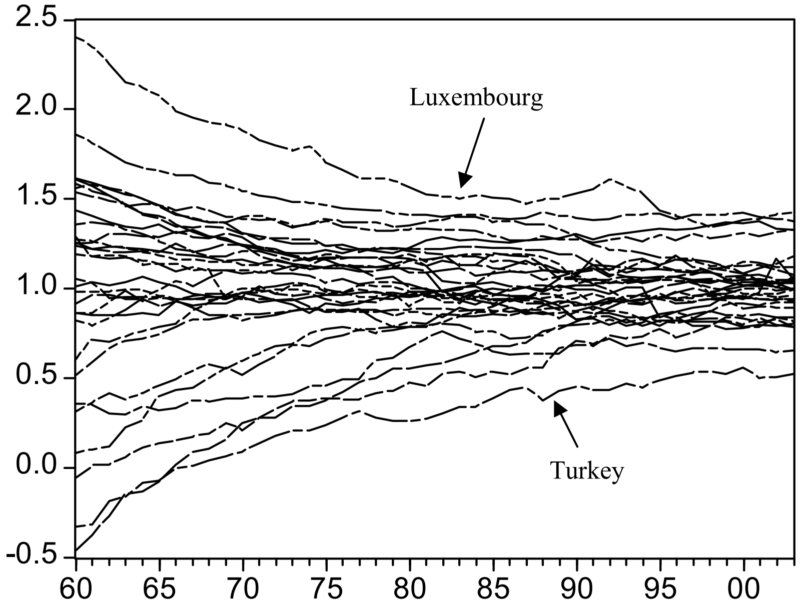


Figure 8: Relative Transition Paths of High-Income Countries

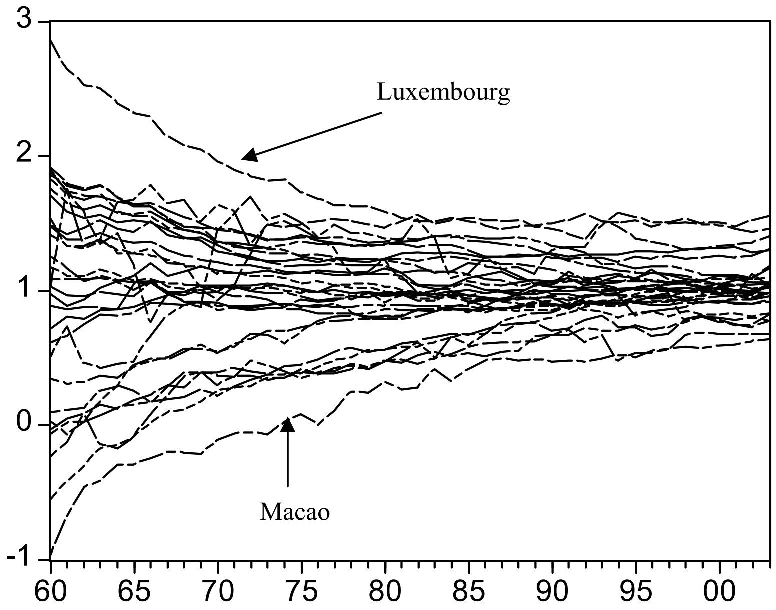
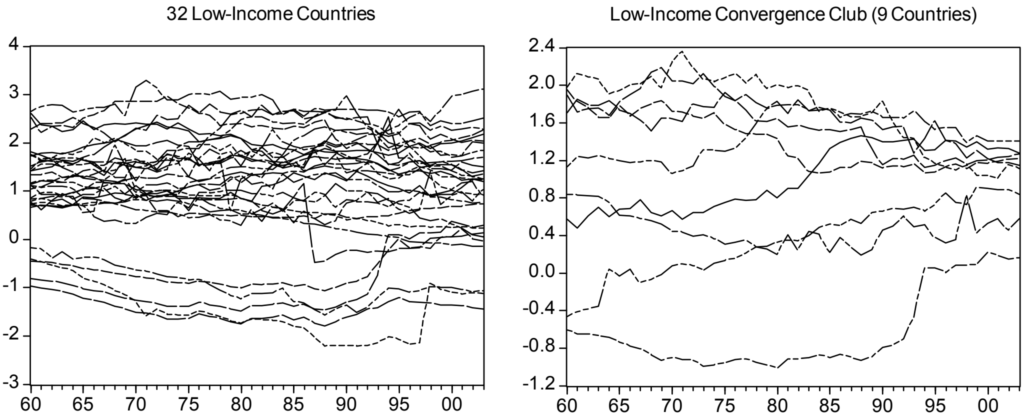



Figure 9: Relative Transition Paths of Low-Income Countries



Institute for International Integration Studies
The Sutherland Centre, Trinity College Dublin, Dublin 2, Ireland